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Flavia Ferranti
Sapienza University of Rome
Giada Daniele
Sapienza University of Rome
Gerardo Ventafridda
Acquedotto Pugliese S.p.A
Giuseppe Sappa
giuseppe.sappa@uniroma1.it

Sapienza University of Rome

Research Article

Keywords: groundwater resources estimation, water budget, climate change, karst spring

Posted Date: November 26th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11702082/v1

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Additional Declarations: No competing interests reported.

GIS-based inverse hydrogeological budget application to evaluate groundwater recharge of the karst aquifer feeding the Sanità Spring (Caposele, South Italy)

Flavia Ferranti[1], Giada Daniele[1], Gerardo Ventafridda[2], Giuseppe Sappa[1]

[1)] Department of Civil, Environmental and Construction Engineering (DICEA), Sapienza University of Rome, 00185 Rome, Italy

[2)] Acquedotto Pugliese S.p.A., Bari, Italy

Corresponding author: giuseppe.sappa@uniroma1.it

Abstract

Estimating groundwater recharge in karst aquifers is a crucial need for sustainable water management under escalating climate pressures in the Mediterranean region and increasing groundwater demand. For this reason, quantifying recharge in these complex hydrogeological settings, where water infiltration is heavily influenced by seasonality, remains challenging due to localized infiltration pathways and missing parameters in conventional surface water balances. To overcome these limitations, spatially discretized inverse water budget approaches offer an alternative by integrating long-term hydro-meteorological datasets with distributed land cover and geological properties. The main objective of this study is to estimate groundwater recharge of the karst hydrogeological basin feeding the Sanità spring at Caposele (NE Campania Region, Southern Italy), the main spring of the Sele River, serving as the key source of the historic Apulian Aqueduct, which provides drinking water to over four million inhabitants, across Puglia (100% of the population), Basilicata (25% of the population) and Campania (2% of the population). For

this reason, in this study the groundwater recharge assessment for the Sanità spring has been carried out by applying a GIS-based Inverse Hydrogeological Budget methodology proposed by Civita, using climate parameters for the period (2000-2025), providing a reproducible framework to support water management in this vulnerable karst catchment area.

Keywords: groundwater resources estimation; water budget; climate change; karst spring

1 Introduction

Karst aquifers constitute some of the most strategic and highly vulnerable groundwater resources globally, supplying drinking water to approximately a quarter of the world's population [1, 3]. Due to the coexistence of highly conductive conduit networks and a low-permeability fissured matrix, karst systems exhibit severe heterogeneity and anisotropy leading to rapid hydrodynamic responses to precipitation events and highly localized flow paths [4]. In the current scenario of global climate change, marked by shifting precipitation patterns and prolonged droughts which can affect water resources availability [5], accurately quantifying karst groundwater recharge is crucial for ensuring sustainable water resource management and assessing aquifer availability [6]. Over the past several decades, the scientific community has developed a wide set of methodologies for groundwater recharge estimation [7, 8]. For karst groundwater systems, characterized by high secondary permeability, well-developed conduit networks and complex interactions between surface and subsurface hydrological processes, it is not possible to properly quantify all the parameters involved in defining the traditional water budget method (i.e., natural inflows and outflows, water exchanges between surface and groundwater,

47 artificial recharge and withdrawals) [9]. To overcome these constraints, the Inverse
48 Hydrogeological Water Budget is as an effective alternative [7, 10, 11, 12]. In fact, by
49 utilizing robust discharge time-series of precipitation and temperature, as the primary
50 system output, the Inverse Hydrogeological Water Budget back-calculates effective
51 infiltration (I_{eff}), leading to a reliable estimation of the average annual groundwater
52 resources, not hindered by any hypothesis about the mechanisms that control the
53 individual components.
54 This paper deals with results coming from hydrogeological studies carried on the Sanità
55 spring at Caposele (NE Campania Region, Southern Italy), a strategic water resource and
56 infrastructural asset of national significance, draining the Cervialto massif karst aquifer, a
57 regional-scale hydrogeological reservoir of exceptional yield, situated in the
58 Mediterranean basin. The Sanità spring discharges a mean annual flow rate of 3.7 m^3/s
59 (2000-2025), entirely dictated by the local climate [13], and is the primary supply source
60 for the Apulian Aqueduct, which provides drinking water to over four million inhabitants
61 belonging to the regions of Puglia, Basilicata and Campania.
62 Due to its critical role, the hydrogeological behavior of the Sanità hydrogeological system
63 requires advanced quantification to cope with modern environmental pressures. The
64 intensification of extreme weather events [13, 14], characterized by long-lasting dry
65 periods interrupted by high-intensity, short-duration rainfall, significantly affects the
66 infiltration processes, potentially altering the balance between conduit-mediated quick-
67 flow and matrix-mediated base-flow recharge.
68 This study focuses on the application of the Inverse Hydrogeological Water Budget to
69 evaluate the effective infiltration (I_{eff}) feeding the Sanità spring hydrogeological catchment

area. Using a multi-decadal dataset of monthly precipitation and temperature records (2000–2025), the active recharge processes of the Cervialto karst massif were characterized to validate the reliability of inverse water balance modelling in a high-discharge, conduit-dominated karst system and to assess the resilience and sensitivity of the Cervialto aquifer system to escalating climate variability. The outcomes of this research provide critical insights for optimizing regional groundwater allocation strategies in Southern Italy and offer a scalable methodological workflow applicable to complex, high-yield karst systems globally.

2 Background

The first geological and hydrogeological investigations date back to the studies [15], which reconstructed the structural framework of the Cervialto massif and identified the main hydrogeological boundaries of the recharge area feeding the Sanità spring. These studies have shown that groundwater circulation is strongly controlled by tectonic structures and karstification processes affecting the Mesozoic carbonate formations of the Picentini Mountains [16].

During the following decades, research progressively shifted from geological characterization to quantitative assessment of this aquifer system. A major contribution was provided by Fiorillo and co-workers, who analyzed the long-term discharge records of the Sanità spring, available since the early 1920s. By combining statistical analyses of spring discharge and precipitation data, Fiorillo demonstrated the so-called memory effect of karst aquifers, showing that spring discharge is controlled not only by precipitation occurring during the current hydrological year but also by groundwater recharge

accumulated during previous years. This characteristic makes this aquifer highly resilient during prolonged drought periods.

A further step toward understanding the hydrodynamic behavior of the spring was achieved by Fiorillo through recession curve analysis of spring discharge during low-flow periods [17, 19]. By determining recession coefficients, the author demonstrated that these parameters are directly related to the volume of groundwater stored within the aquifer, allowing the characterization of aquifer depletion processes and the estimation of its storage capacity. This approach provided valuable information for groundwater resource management during dry periods.

The quantitative assessment of the hydrogeological water budget was further developed by Civita [19], who proposed a conceptual model to estimate the dynamic groundwater resources of the Sanità Spring. The study highlighted the exceptionally high infiltration capacity of the Monte Cervialto carbonate aquifer, about 138.12 Mm^3 (1930-1942), typical of highly fractured and karstified limestone formations, and emphasized the crucial role of groundwater storage in maintaining relatively stable spring discharge even during periods of reduced rainfall.

Overall, the investigations focused primarily on geological mapping and structural characterization of the carbonate massif, whereas more recent studies have adopted quantitative hydrogeological water budget models supported by long-term hydrological and climatic datasets. Current research consistently identifies the Sanità Spring as a large and highly productive karst aquifer characterized by high storage capacity, significant hydrological memory, and a strong dependence on effective groundwater recharge. These findings provide the scientific basis for sustainable groundwater management and

115 for evaluating the potential impacts of climate variability and climate change on the
116 hydrogeological functioning of the Sanità spring aquifer system.

117 3 Geological and hydrogeological setting

118 Sanità spring is located in the upper valley of Sele River in Campania region, Southern
119 Italy, at an elevation of approximately 415 m a.s.l.. Geomorphologically, the area is
120 dominated by steep slopes, deep valleys and well-developed karst landforms holding the
121 Cervialto massif, which is characterized by carbonate ridges, high annual rainfall, and
122 significant groundwater resources. The drainage of this aquifer system occurs primarily
123 through Sanità spring which represents the primary natural discharge of this
124 hydrogeological system.
125 The study area is located in the axial zone of the Southern Apennines, a fold-and-thrust
126 belt formed during the Neogene orogeny due to the collision between the African and
127 European plates [21]. The primary geological reservoir feeding Sanità spring is the
128 Cervialto carbonate massif, which consists of a thick continuous Mesozoic succession
129 (Triassic to Cretaceous) dominated by well-stratified to massive dolomites and dolomitic
130 limestones in the lower stratigraphic portions; and highly fractured neritic limestones
131 (bioclastic and detrital) in the upper sequences [21, 23] (Fig. 1). The tectonic setting is
132 highly complex, characterized by intense Miocene compressional phases followed by
133 Pliocene-Quaternary brittle extensional tectonics. Consequently, the Cervialto massif is
134 bounded and dissected by a dense network of high-angle normal and strike-slip faults
135 (Fig. 1). These structural discontinuities have intensely fractured the rock matrix, creating
136 preferential pathways for deep karstification and sub-vertical groundwater circulation. The
137 margins of the carbonate massif are juxtaposed against low-permeability orogenic

deposits and Quaternary alluvial-colluvial sediments, which hydraulically close the aquifer and force groundwater discharge at localized overflow points [24]. This highly heterogeneous system forces groundwater to follow complex and involved flow paths through the rock complexes before discharging at the surface by Sanità spring.

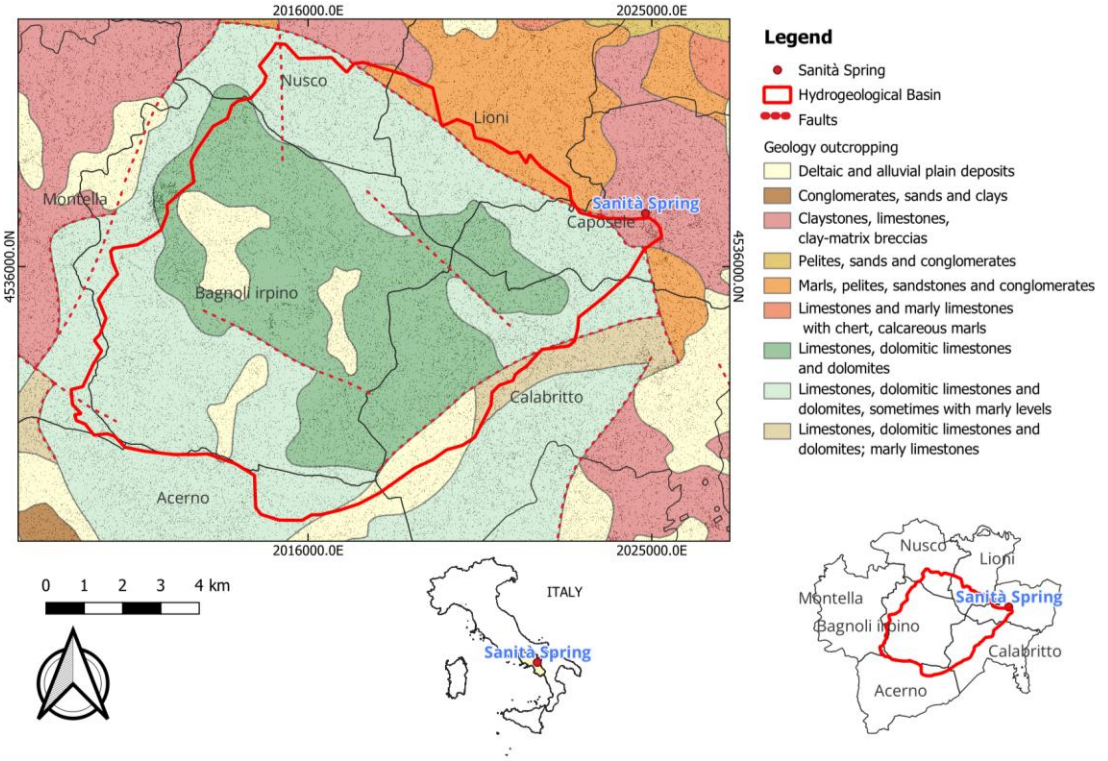
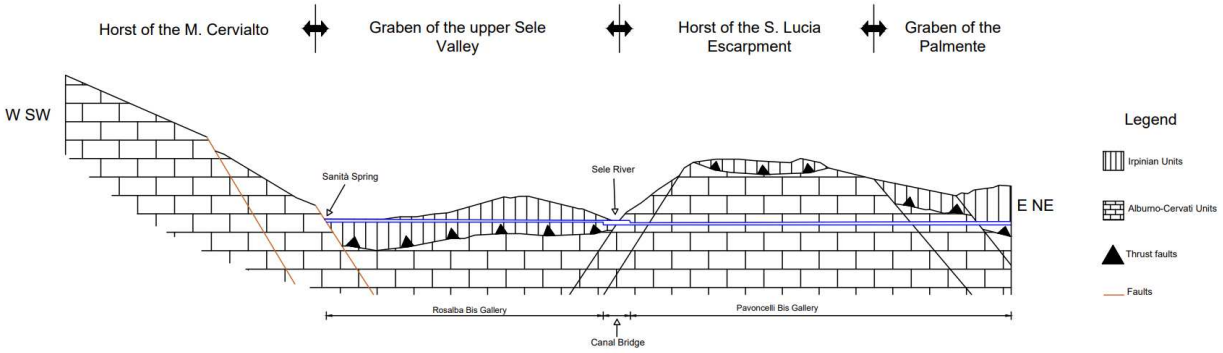


Fig. 1 Simplified geological map of the study area

Based on literature data [17, 20, 25], the Sanità spring hydrogeological basin was conservatively estimated to extend over an area of approximately 110 km², consequently, Cervialto massif, in its comprehensive entirety, can be considered a carbonate aquifer, constituting the sole reservoir feeding the Sanità spring [16, 18] (Fig. 1). The catchment area is characterized by horst-and-graben structures, representing first and second-order tectonic highs and lows [26]. The primary western horst is defined by Mt. Cervialto (to the north) and the Boschetiello-Polveracchio Mts. (to the south), whereas the primary eastern

151 horst corresponds to the Marzano-Ogna Mts. The main graben, naturally located between
152 the highs, is that of the middle and upper Sele Valley (Fig. 2).



153

154 **Fig. 2** Sanità spring geological cross section

155 Figure 3 shows the flow rate (Q) trends from January 2000 to December 2025,
156 compared with rainfall data recorded at the Caposele station. Groundwater flow within
157 this system is governed by dual-porosity dynamics: a highly conductive network of karst
158 conduits and macro-fractures manages the rapid transmission of groundwater (quick-
159 flow), while a diffuse system of micro-fissures and matrix porosity acts as the primary
160 storage reservoir (base-flow). Sanità spring serves as the main basal overflow point of
161 this hydrogeological structure, showing a perennial hydrological regime, with a mean
162 annual discharge of approximately 3.7 m^3/s (2000-2025) and minimal seasonal
163 fluctuations compared to other Apennine karst sources. This baseline stability indicates
164 a massive regulating capacity of the saturated zone (phreatic volume) within the inner
165 core of the massif [13, 18].

166 This spring acts as a hydrogeological barrier where the highly permeable Cretaceous
167 limestones abruptly transition into the low-permeability terrigenous facies of the
168 variegated clays and Miocene flysch formations [27, 28]. This sharp hydraulic contrast
169 blocks lateral groundwater flow, forcing the water table to the surface. Due to its

exceptional and reliable yield, the Sanità spring has been chosen since the early 20th century to feed the Apulian Aqueduct, representing a critical, strategic infrastructure for the socio-economic water supply of southeastern Italy.

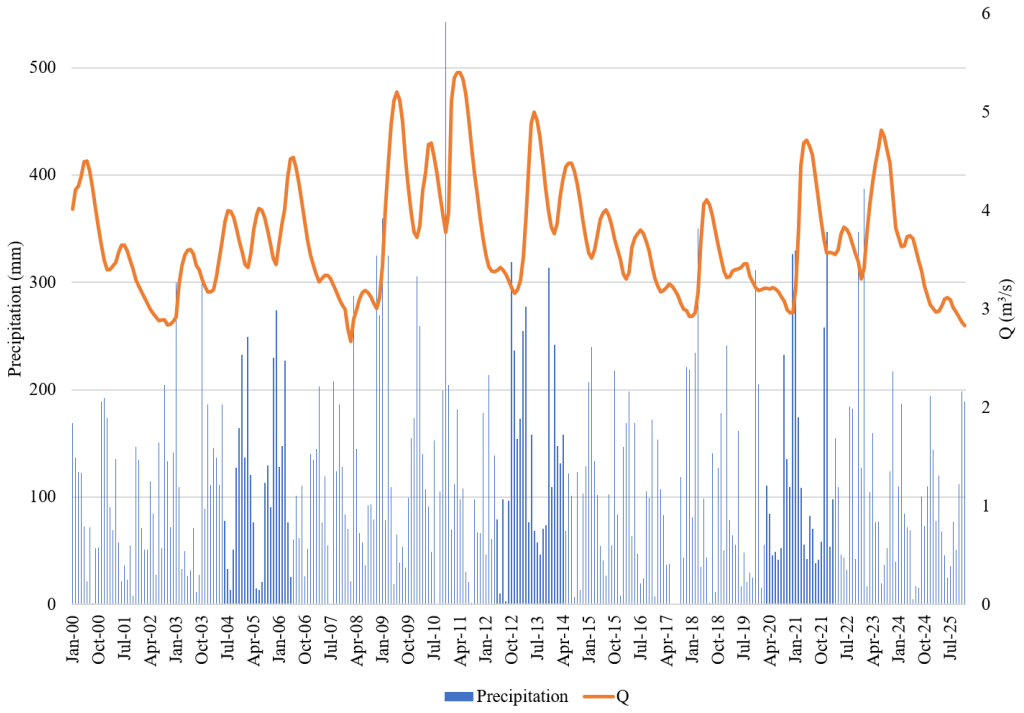


Fig. 3 Hydrological Regime of the Sanità Spring (2000-2025), Caposele Rainfall Station

3. Results and Discussion

To evaluate the effective infiltration in the study area and evaluate aquifer recharge, a distributed Inverse Hydrogeological Water Budget Method was applied to the Sanità spring catchment area [10, 11]. The structural boundaries of the Sanità spring hydrogeological basin have been delineated based on previous hydrogeological literature [13, 20], encompassing a total surface area of approximately 110 km^2. To account for spatial heterogeneity across the catchment, the study domain was discretized into a regular square grid mesh with a spatial resolution of [250m×250m] as this is the dimension considered as the smallest one to give a reliable representation of

morphological features of the area under study. A high-resolution Digital Elevation Model (DEM) [29] served as the foundational framework to link each cell with altitude-dependent meteoclimatic variables. Concurrently, vector geological maps were overlaid onto the grid to assign the dominant outcropping lithology to each individual cell, establishing the spatial framework for surface permeability and infiltration capacity. The distributed water budget was computed cell-by-cell by a GIS support according to the sequential procedure shown in Figure 4.

The key step in applying the Hydrogeological Inverse Budget method [10] is establishing the relationship between rainfall, temperature and elevation across the discretized study area. To evaluate groundwater recharge, rainfall and temperature data for the period 2000–2025 were obtained from the meteorological monitoring network of the Campania Region Civil Protection Multi-Risk Functional Centre.

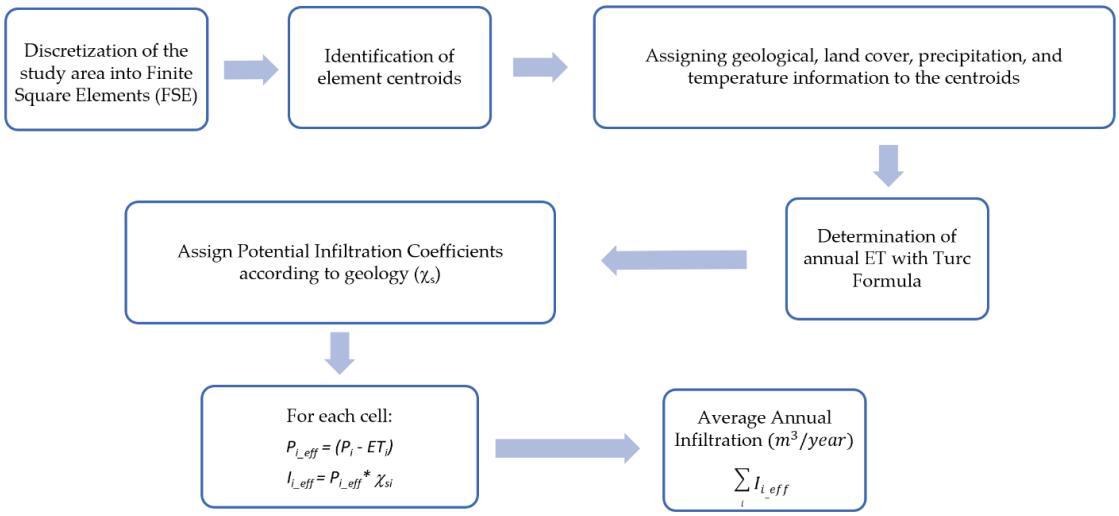


Fig. 4 Flow-chart of the Inverse Hydrogeological Water Budget

Due to the absence of active meteorological stations directly located within the high-altitude sectors of the Cervialto Massif (which peaks at 1809 m a.s.l.), in this study the

meteorological stations, positioned exclusively along the peripheral flanks of the massif, reported in Table 1 were used.

Table 1. Designed meteorological stations

Meteorological stations	Period of observations	Elevation (m a.s.l.)	Geographical coordinates	
Bagnoli Irpino	2000-2025	428	40.83°N	15.08° E
Caposele	2000-2025	460	40.82°N	15.22° E
Cassano Irpino	2000-2025	730	40.88°N	15.03° E

To overcome the lack of high-altitude instrumental measurements, Average Annual Precipitation (AAP) and Temperature (AAT) were spatialized across the Digital Elevation Model (DEM) of the hydrogeological basin (Table 2) using elevation-dependent regressions derived from the surrounding network (eq. 1-2):

Table 2. Average annual precipitation (AAP) and temperature (AAT) over the 2000–2025 observation period

Meteorological stations	AAP (mm)	AAT (°C)	Elevation (m a.s.l.)
Bagnoli Irpino	1332.93	13.81	428
Caposele	1343.01	12.56	460
Cassano Irpino	1479.961	13.39	730

$$P(z) = 392.92 \cdot z^{0.2011} \quad (1)$$

$$T = -0.006 \cdot z + 16.376 \quad (2)$$

For temperature regionalization, to avoid local microclimatic biases (such as valley inversion phenomena observed between peripheral stations), a regional lapse rate of $-0.60\,^{\circ}$C per 100 m elevation gain, widely established for the Southern Apennines karst massifs [30], was coupled with the baseline thermal readings of the network. This temperature lapse rate strongly reflects regional atmospheric lapse dynamics in the Southern Apennines and prevents the overestimation of Potential Evapotranspiration (ETP), calculated via the Turc formula, over the high-altitude karst terrain, avoiding overestimation of losses on the high-altitude karst plateaus (e.g. Piano Laceno).

The study area shows the typical Mediterranean rainfall regime, with the highest values between fall and winter and minimum values in summer, and temperature varies considerably with altitude (Fig. 5).

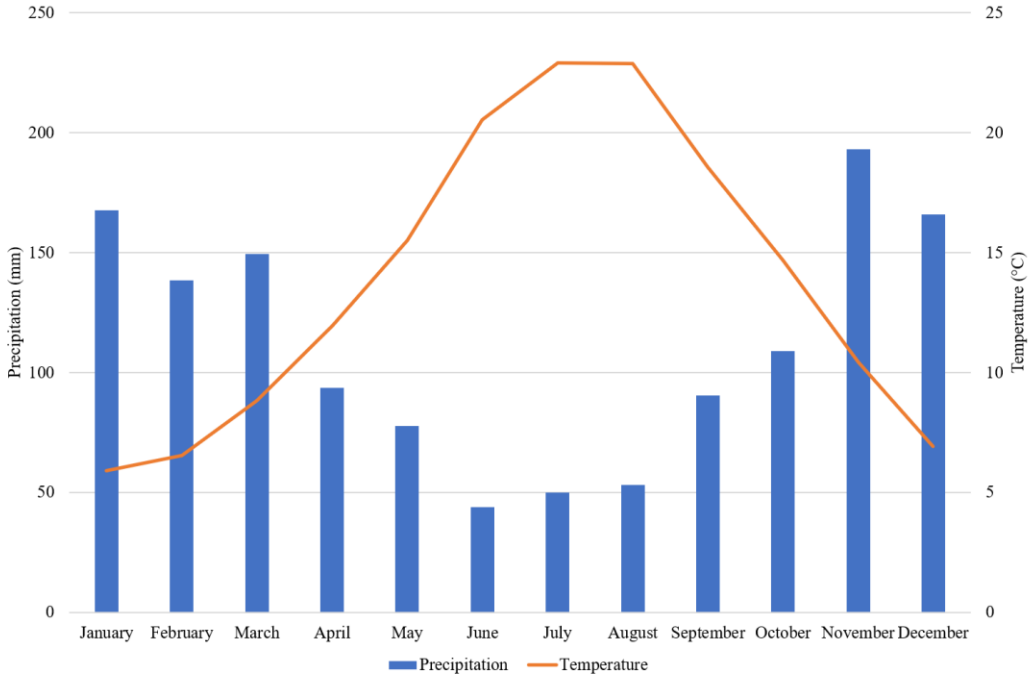


Fig. 5 Mean monthly precipitation and temperature (Caposele meteorological station)

An analysis of the precipitation record (2000–2025) shows a hydro-climatic anomaly during the 2024–2025 biennium (Fig. 6). While the long-term baseline average annual precipitation for the Caposele basin stands at 1332.93 mm/yr (2000-2025), the recent two-year period was characterized by a rainfall deficit. Particularly, total annual precipitation is 1038.60 mm in 2024 and 1144.48 mm in 2025, representing significant negative deviations of -22% (-294.33 mm) and -14.1% (-188.44 mm) relative to the multi-year average, respectively. Remarkably, 2024 ranked as the third driest year in the 26-year monitoring history, surpassed in drought severity only by 2001 (951.60 mm) and 2017 (1020.90 mm). The 2024 deficit was driven by marked shortfall in autumn and early spring precipitation, the useful window for effective groundwater recharge in Southern Apennines karst massifs. In 2024, rainfall during March (84.60 mm), October (73.00 mm)

and November (110.20 mm) was significantly lower than their respective monthly historical averages (149.32 mm, 108.99 mm and 193.02 mm, respectively) (Fig. 7).

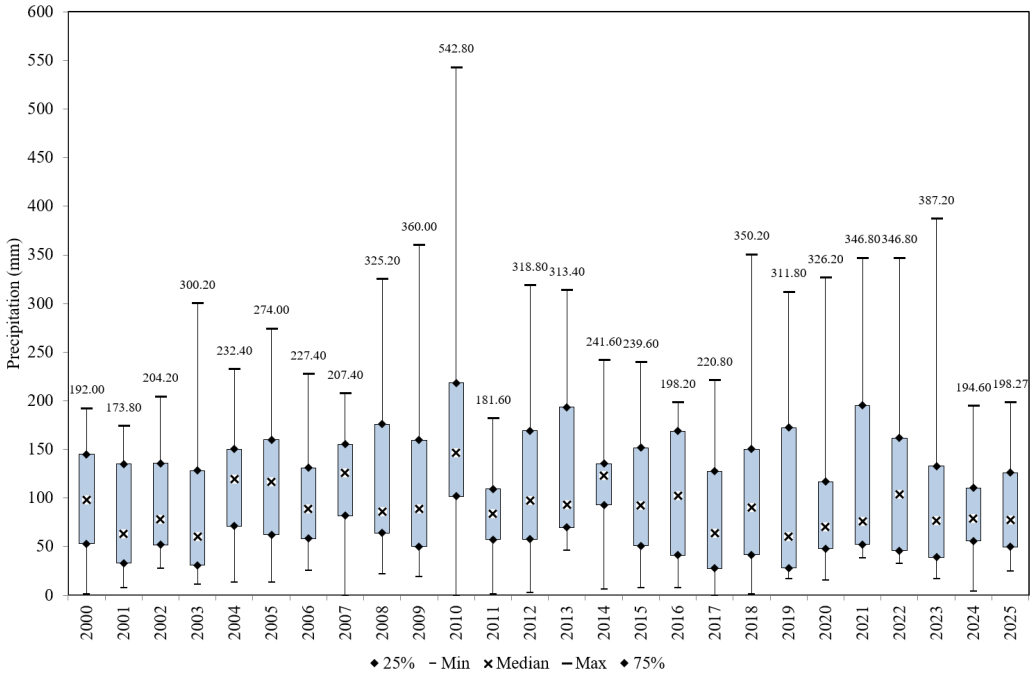


Fig. 6 Box plot of annual precipitation (2000-2025) (Caposele meteorological station)

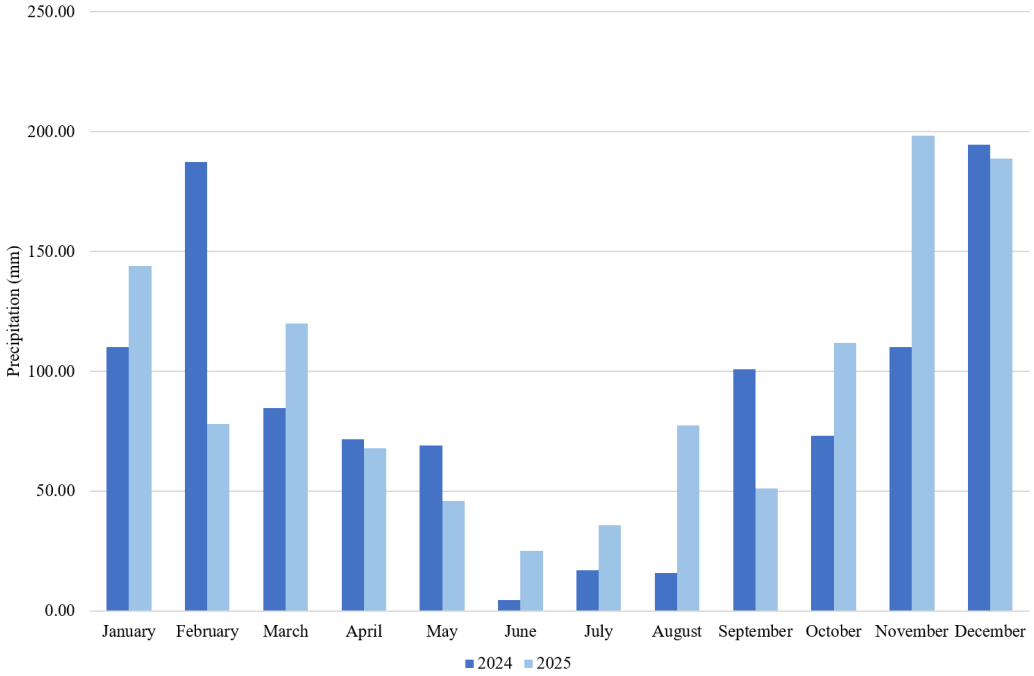


Fig. 7 Average monthly precipitation (2024-2025) (Caposele meteorological station)

Although 2025 shows a modest recovery (1144.48 mm), probably due to the late-autumn events in November (198.27 mm) and December (188.82 mm), the cumulative multi-month rainfall shortage directly impacted the water table, accounting for the observed depletion in spring discharge (Q) at the Sanità di Caposele spring complex (Fig. 8). The historical maximum discharge value has been recorded in 2011, reaching 5.40 m^3/s, following the 2010 precipitation peak (542.80 mm). By 2025, the lack of extreme rainfall events (Fig. 7) led to the lowest recorded peak discharge of the entire series (3.12 m^3/s). These results reflect the high storage capacity of this carbonate aquifer dominated by baseline conditions rather than flash runoff [17, 19] (Fig. 8).

To assign the Annual Average Precipitation (AAP) to each grid cell, a precipitation–elevation relationship was established by analyzing the mean annual rainfall data from the three monitoring stations selected for the water budget estimation.

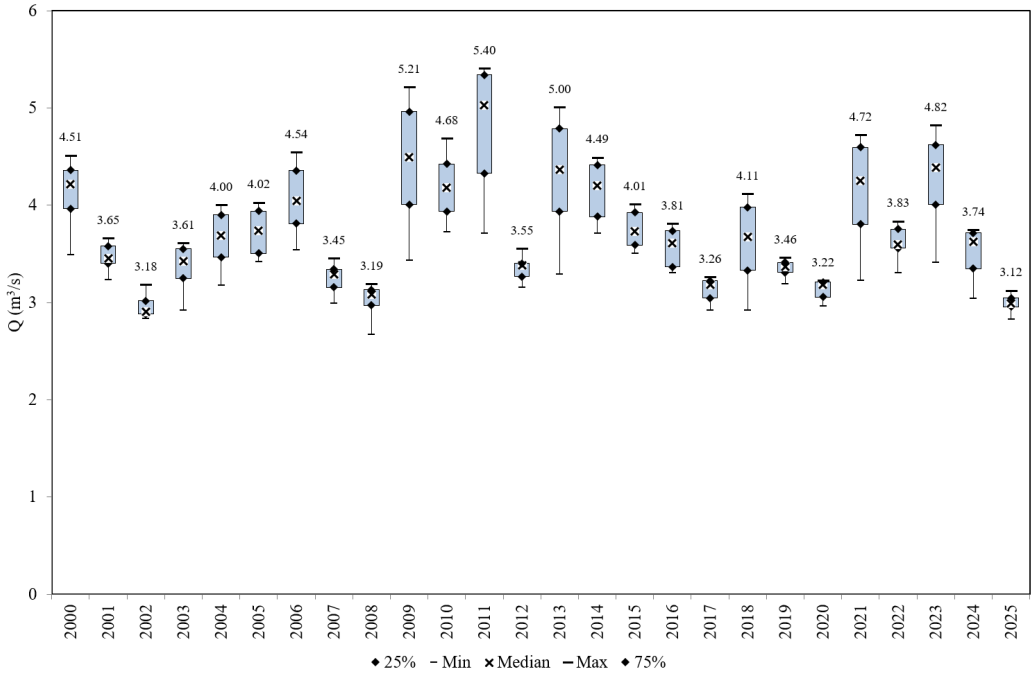
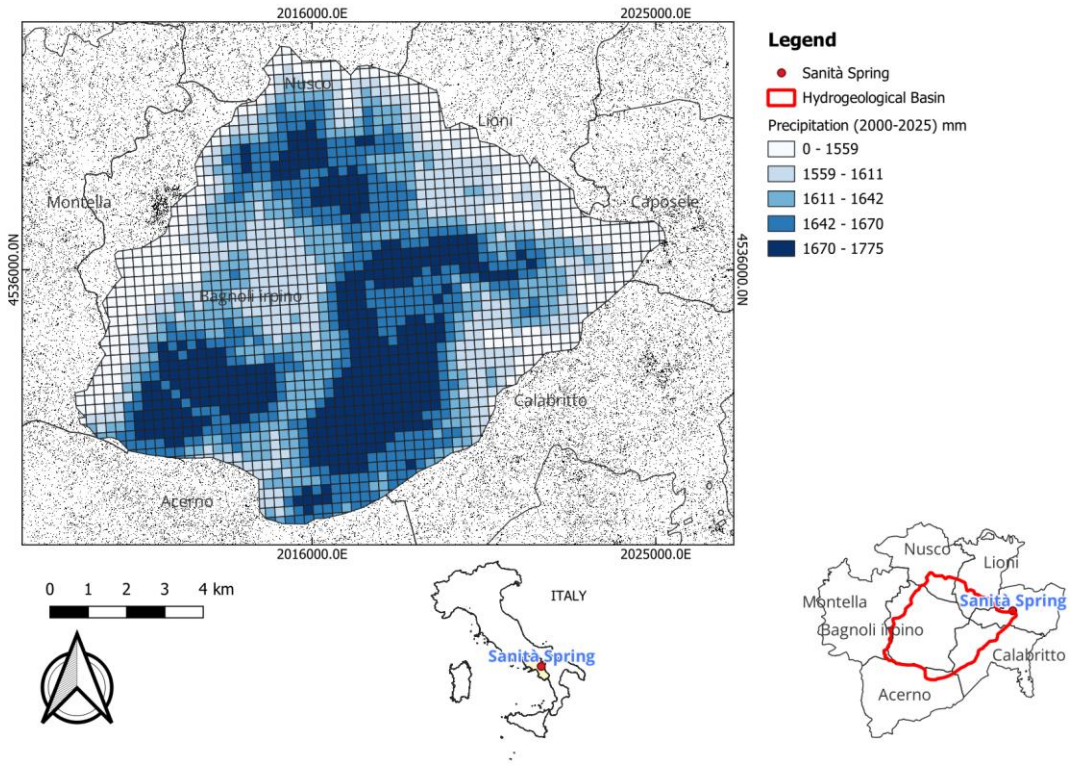


Fig. 8 Box plot of Sanità spring flow rate (2000-2025)

255 The lowest precipitation values are localized along the western and eastern sectors
256 of the basin, whereas the central area is characterized by rainfall maxima exceeding 1700
257 mm/year (Fig. 9). The geographical setting of the Sanità spring, situated on the eastern
258 margin of the basin, is of hydrogeological significance; the spring is sustained by
259 groundwater flow originating from the central sectors of the massif, which are
260 characterized by the highest AAP values.

261 The temperature data for the considered reference period (2000–2025) were
262 recovered from the database of the Functional Multi-Risk Centre of the Campania Region.
263 To couple each grid cell with its respective thermometric values, a mean temperature–
264 elevation relationship (thermal lapse rate) was applied, derived from the analysis of the
265 three stations used for the water budget computation.

266



267

268 **Fig. 9** Spatial distribution of rainfall (2000-2025)

The Mean Annual Temperature map (Fig. 10) of the catchment feeding the Sanità spring displays a distinct thermal gradient. The lowest temperature values are concentrated across the central sector of the massif. This spatial distribution plays a critical role in the hydrogeological water budget of the basin, as the lower temperatures recorded at higher altitudes significantly reduce evapotranspirative losses.

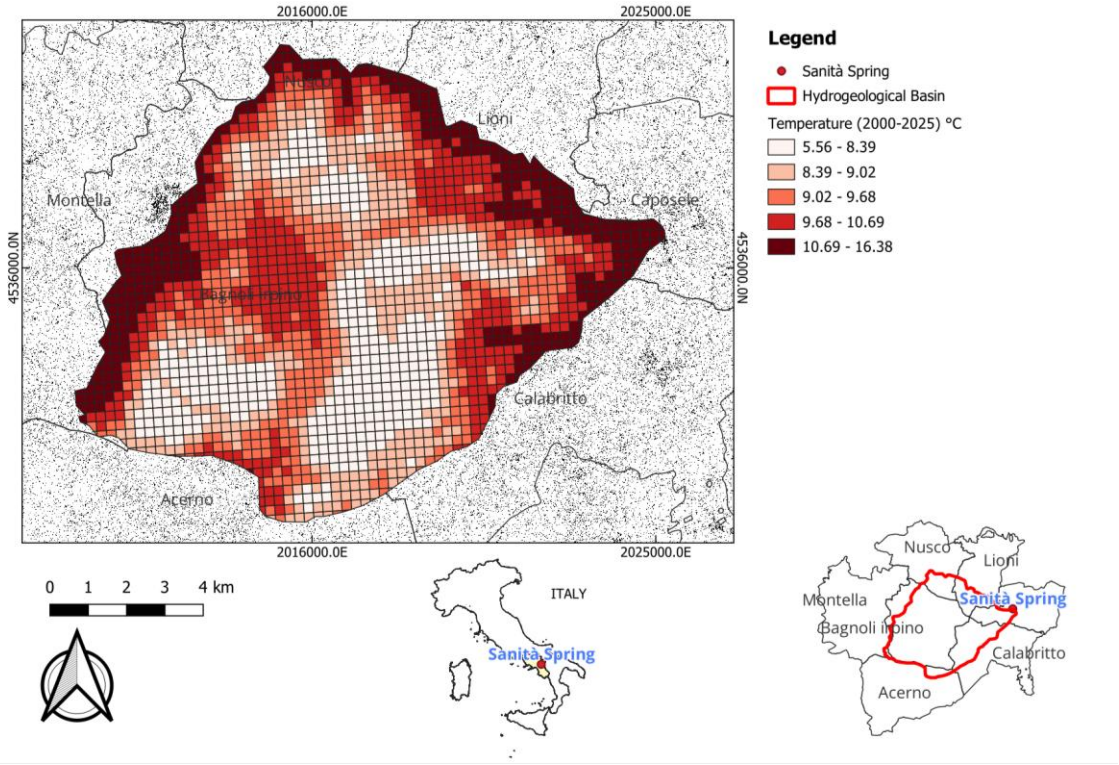


Fig. 10 Spatial distribution of average annual temperature (2000-2025)

Actual Evapotranspiration was estimated using the Turc formula [31, 32], which computes water loss as a function of the calculated annual precipitation and temperature fields (Fig. 11).

The potential water available for runoff and infiltration was determined for each cell as the direct difference between precipitation and evapotranspiration. To estimate the infiltration and as a consequence of it, groundwater recharge in the area, it has been made match between rainfall estimation and outcropping rock masses hydrogeological

properties, by the estimation of a potential infiltration factor (χ_s), set up taking into account properties of outcropping rock masses. The choice of χ_s has been made considering the specific guideline offered by the method authors as the experience carried out by the authors in previous studies [11, 33].

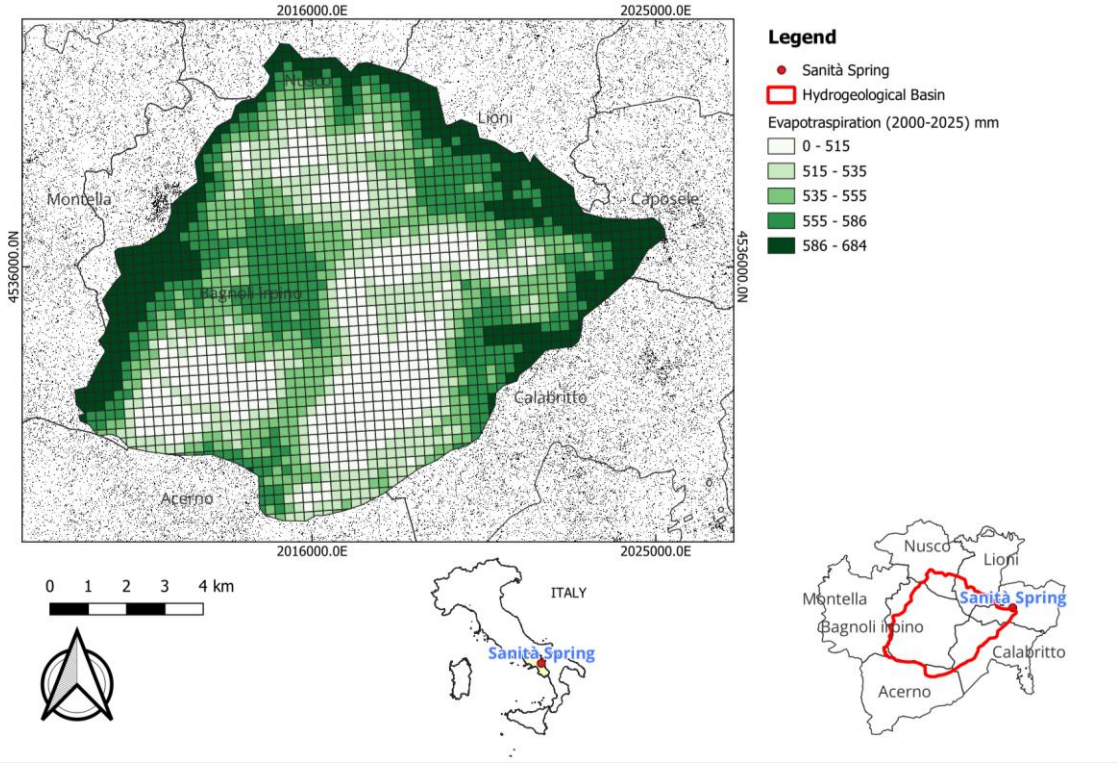


Fig. 11 Spatial distribution of actual evapotranspiration (2000-2025)

According to outcropping lithology, the outcropping rocks include the following formations, which have been assigned an average χ_s value as represented in Table 3.

Table 3. Potential Infiltration Coefficients according to geology (χ_s)

Type	χ_s
Deltaic and floodplain deposits; Holocene	0.4
Marls, pelites, sandstones, and conglomerates, including in turbidite facies	0.5
Mudstones, limestones, clay-matrix breccias; turbiditic sandstones and pelites	0.3
Limestones, dolomitic limestones, and dolostones; sometimes with bauxitic horizons at the base	0.8
Limestones, dolomitic limestones, and dolostones, sometimes with marly layers	0.6
Limestones, dolomitic limestones, and dolostones; marly limestones, marls, and bituminous argillites	0.5

The total annual effective infiltration volume per cell (I_{eff}) was quantified by multiplying the effective infiltration depth by the physical surface area of the elemental grid cell. These distributed cell values were subsequently spatially aggregated across the basin to compute the total cumulative recharge volume of 77.90 Mm^3/year (Fig. 12).

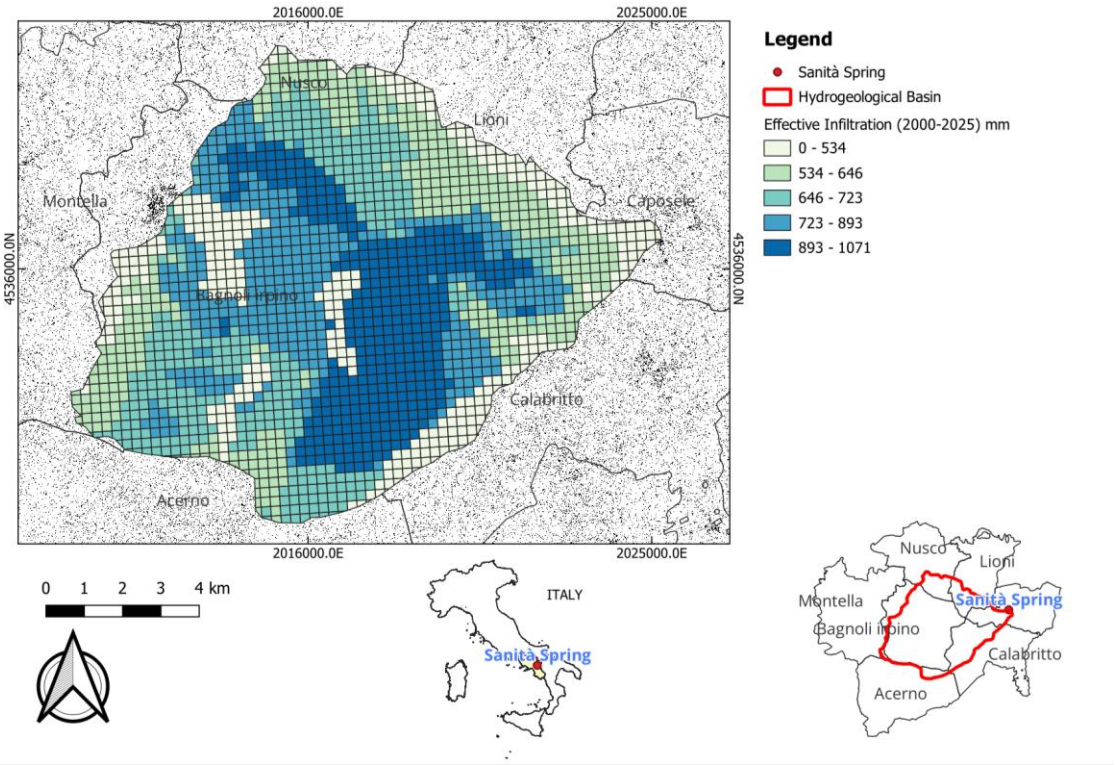


Fig. 12 Spatial distribution of effective infiltration (2000-2025)

Spatial analysis reveals significant heterogeneity in the hydro-meteorological parameters across the Sanità spring recharge basin. The Annual Average Precipitation (AAP) exhibits a strong orographic dependency, with values exceeding 1700 mm/year in the central elevated sectors, while dropping to lower thresholds along the northern and eastern margins. Conversely, Average Annual Temperature values demonstrate a clear negative thermal gradient, reaching their minimum within the central mountain massif. This spatial distribution plays a critical role in mitigating water loss, as lower temperatures at peak altitudes effectively suppress evapotranspiration rates. Consequently, the central

306 and eastern portions of the basin exhibit noticeably lower atmospheric water losses. In
307 contrast, the highest effective infiltration (I_{eff}) values are concentrated in the south-central
308 sector, highlighting this area as the primary recharge zone characterized by high potential
309 infiltration coefficients (χ_s) linked to the outcropping lithology. Toward the boundaries of
310 the basin, infiltration decreases sharply as surface runoff becomes dominant due to
311 topographically driven lateral flows. The application of this methodology highlights the key
312 role of the hydrogeological structure feeding the Sanità Spring as a strategic water
313 resource for Southern Italy, yielding a mean annual active recharge of approximately 78
314 Mm^3/year over a 26-year observation period (2000–2025)."

315 Due to the empirical derivation of the potential infiltration coefficients (χ_s) assigned to
316 the hydrogeological complexes, a sensitivity analysis was conducted to evaluate the
317 impact of parameter uncertainty on the estimated annual groundwater recharge I_{eff}. The
318 baseline χ_s values derived from literature were varied by ±10% (Table 3). Because
319 effective infiltration is directly proportional to χ_s, the variation propagates linearly into the
320 water balance equation:

321 $$I_{eff\pm 10\%} = \sum \left[(P_i - ETP_i) \cdot \left(\chi_s \cdot (1 \pm 0.10) \right) \cdot A_i \right]$$

322 where P_i, ETP_i and A_i represent precipitation, potential evapotranspiration, and cell area
323 across the basin grid, respectively. In Table 4 are shown the results of a sensitivity
324 analysis of mean annual groundwater recharge to a ±10% variation in potential infiltration
325 coefficients (χ_s).

326 The sensitivity analysis presented in Table 4 demonstrates the linear response of
327 groundwater recharge to variations in the potential infiltration coefficient (χ_s). A ±10% shift

in c_s leads to an absolute variation of approximately ±7.01 to 7.79 Mm^3/yr compared to the baseline recharge of 77.90 Mm^3/yr. This total uncertainty margin of 14.80 Mm^3/yr highlights the critical importance of accurate parameter calibration, as relatively minor variations in empirical infiltration coefficients propagate into substantial differences in estimated annual groundwater availability for basin-scale water resources management.

Table 4 Sensitivity analysis of mean annual groundwater recharge to a ±10% variation in potential infiltration coefficients (χ_s).

Potential Infiltration Coefficients	Active Recharge (Mm^3)
χ_s	77.90
$\chi_{s+10\%}$	84.91
$\chi_{s-10\%}$	70.11

Comparison of the mean annual effective infiltration (77.90 Mm^3/yr over the period 2000–2025 across the 110 km^2 catchment area), with the calculated multi-year depletion volume (36.67 Mm^3/yr), over the same period, highlights the regulating capacity of the aquifer matrix. The depletion volume accounts for approximately 47% of the total annual effective infiltration, highlights the high regulation capacity and hydrological memory of the Cervialto karst aquifer. Approximately 47% of the infiltrated water enters the deep slow-release storage reservoir (baseflow), ensuring the perennial regime and stability of the spring even during prolonged drought periods. The remaining 53% feeds the rapid response (quickflow) conveyed by the main karst conduit network during seasonal rainfall peaks or contributes to regional lateral groundwater outflows.

Based on the measured mean annual flow rate of 3.70 m^3/s over the 2000–2025 period, the Sanità Spring discharges an average annual volume of about 116.76 Mm^3/yr. The total spring discharge thus exceeds the local effective infiltration calculated within the conventional 110 km^2 boundary by approximately 38.86 Mm^3/yr. This volumetric

discrepancy can be related to a conservative estimation of the recharge area, to lateral groundwater contributions from adjacent carbonate structures (e.g., the Laceno plateau and contiguous sectors of the Picentini Mountains), and probably to an underestimation of the real orographic rainfall and snowfall accumulation across the uninstrumented upper karst plateaus and peaks that exceed the values estimated by regional elevation regressions.

Conclusion

This study applied a spatially discretized inverse hydrological budget method using a 250m×250m mesh grid to evaluate the hydrodynamic budget of the Sanità spring. The integration of long-term meteorological datasets (2000–2025) and digital elevation model made easy a sound evaluation of spatial fluxes. Results conclusively show that the Sanità spring, located at the eastern margin of the basin, is strategically sustained by subsurface groundwater flow coming from the central sectors of the massif. This specific recharge mechanism is highly effective due to the compound effects of maximum precipitations, reduced evapotranspiration, thanks to lower high-altitude temperatures, and high bedrock permeability in the core recharge zones. Last, but not least, this grid-based approach provides a scientifically rigorous and reproducible framework for groundwater resource management in this area, offering critical insights into the hydrodynamic preservation of strategic karst aquifers and giving interesting highlights on the different contributions to the Sanità Spring flowrate.

Declarations

Competing interests. The authors declare that they have no competing interests.

Authors' contributions All authors contributed to the study conception, design, data collection, and manuscript preparation. Giuseppe Sappa contributed to conceptualization, research design, and original draft preparation. Flavia Ferranti contributed to conceptualization, original draft preparation, manuscript writing, and review. Giada Daniele contributed to formal analysis, manuscript review and editing. Gerardo Ventafridda contributed to data collection and manuscript review. All authors read and approved the final manuscript.

Funding

This research received no external funding.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Acknowledgment

The authors would like to thank Acquedotto Pugliese S.p.A. for providing essential data supporting this research.

Declarations

Ethical approval

Not applicable. This study did not involve human participants, human data, or animals.

Consent to participate

Not applicable. This study did not involve human participants.

Consent for publication

Not applicable. This manuscript does not contain any individual person's data, and images.

Competing interests

The authors declare no competing interests

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